Photoconductivity- An Overview

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Abstract

Optoelectronic devices have been an integral part of modern society. The optoelectronic devices covers wide range of applications such as energy, sensors, communication, healthcare, security, industries etc. There are many techniques to characterize the optoelectronic devices, among that photoconductivity measurement is a versatile technique to understand transport phenomena of carriers in light. Photoconductivity is the tool which analyze the nature of conductivity, mobility of free excess carriers, excess carrier density, distribution of localized states (defects distribution) etc. In the present article, the photoconductivity measurement techniques are discussed.

Introduction

Photoconductivity measurement has been employed to probe electrical and optical properties of materials [1–6]. It is the process of increase in electrical conductivity by absorption of photons with energy equal to or greater than band gap energy of the material. The conductivity of a material changes by varying free carrier density and mobility. The rate of electron-hole pair generated, minority carrier life time and transport mechanism are also important parameters to influence the photoconductivity.

When a photon of suitable wavelength incident on a given material, free electrons–hole pairs are generated.The photogenerated carriers may recombine via shallow localized states such that electrons falling in to these states rapidly re-excite thermally in to conduction band. While the electrons falling in to deeper lying states known as recombination centers more likely to capture a free hole rather than thermally re-excitation. If the recombination or capture process terminating photoconductivity is radiative, luminescence emission results. Thusluminescence measurements provide useful information about critical steps involved in the mechanism of photoconductivity. There are several techniques like steady state, transient photoconductivity, surface voltage, spin dependent recombination, time resolved photoconductivity etc. available for the investigation of semiconductors tends to be disorder and have short free carrier life time, these kind of the materials usually prepared as thin film and are widely used in optoelectronics application such as solar cell, thin film transistors, transducers, photosensors etc. Photoconductivity measurement can be a powerful tool to provide a deep insight to study physical phenomena such as absorption, photogeneration, recombination, charge transport and electron-photon interaction etc.

Steady state photoconductivity

In steady state photoconductivity (SSPC)[7–10], monochromatic light is used to generate excess electron-hole pairs which leads to change in conductivity

$$\Delta\sigma_{ph} = e(\mu_n \Delta n + \mu_p \Delta p) \quad (1)$$

where e is charge and μ_p is mobilityof hole, $\mu_n$is mobility of electron and $\Delta\sigma_{ph}$ is known as steady state photoconductivity. In SSPC a potential difference is applied across the sample of length L having cross section A and photocurrentI_{ph} is measured and the corresponding photoconductivity is given by $\sigma_{ph} = I_{ph}/AF$ where F is applied electric field (F=V/L). Many of the photogenerated charge carriers may be trapped at localized states thus a difference in densityof photogenerated charge carriers occurs. The effect of trapping can be seen in mobility value of charge carriers which is lower than the theoretical free carrier value. Thus equation (1) reduced to one carrier equation:

$$\sigma_{ph} = eG(\mu_n \tau_n + \mu_p \tau_p) \quad (2)$$

where the average carrier generation is defined as:

$$G = \eta\phi(1-R)\frac{1-exp(-\alpha d)}{d} (3)$$

where η is quantum efficiency, ϕ is incident photon flux, R is coefficient of reflection, α is absorption coefficient and d is thin film thickness. Photon flux and intensity are related as $\phi = I/E_{ph}$(E_{ph} = energy of incident photon). Generally, η is less than 1 as every photon cannot generate electron-hole pair. The parameters η, ϕ, R depends upon wavelength of illuminating light and material properties as well. Most of the cases, $\alpha d \ll 1$ which represents that thickness (d) of thin film is less than the optical absorption depth '1/α' i.e. incident photon is uniformly absorbed thus G exhibit a constant value rather than average value. Theelectrons recombination rate can be given as:

$$\tau_n^{-1} = b\ (p_0+\Delta p) \qquad (4)$$

where, p_0 is equilibriumhole density and Δp is excess hole densities, b is recombination constant Thus SSPC can be expressed as

$$\Delta\sigma_{ph} \propto \Delta n = G\tau_n = \frac{G}{b\ (p_0+\Delta n)} (5)$$

where, we have used $\Delta p = \Delta n$.

From the above equation, it can be seen that photoconductivity linearly dependent on rate of generation at low excess carrier densities whereas at higher excitation $\Delta n >> p_0$the equation leads to$\Delta\sigma_{ph} \propto G^{1/2}$,the quadratic regime corresponds to bimolecular recombination where intensity of the excited photon is high. Consequently, the variation with photon flux is $\Delta\sigma_{ph} \propto \phi^{\gamma}$.Such recombination is observed in bulk organic and inorganic photoconductors.

Transient photoconductivity

As mentioned earlier number of localized state are present in band gap of the semiconductors which plays an important role to study the photoconductivity of the given material.Due to the presence of these localized states which act as recombination centers as well as traps depending on their position with respect to Fermi level give rise to multiple trapping before the recombination regimes. Transient photoconductivity is characterizes dispersive transport of excess carriers in these localized states with respect to time due to multiple trap centers. Using the density of states, many of the parameters that characterize transport and recombination can be determined in monomolecular (MR) and bimolecular (BR).

Crystalline semiconductor consist of two level defects which are away from conduction band edge by the amount k_BT and from each other. In the presence ofexternal field at time t_0 the photocurrent initially increases as free carriers move in delocalized states in conduction band but with the passage of time,a decrease in drift velocity is observed due to trapping. Trapping time is less than the release time in case of highly disordered semiconductors. If continuous distribution of localized states is in the range of several $k_BT$then continuous decrease in photocurrent will be observed until a steady state is reached. Thus spectrum of localized states energy can be measured.

It is also found that spread in release time may be due to distribution of distances between localized states. Thus dispersion may arise due to multiple trapping which provides the information of density of states. If dispersion arises due to hopping, the spatial distribution of localized states can be analyzed. To study the cause of dispersion we need to perform a photo-induced optical absorption experiment.

Microwave Photocurrent Decay Technique

The main advantage of using this technique is non-measurement[11]. Deposition of electrodes on the sample to measure photoconductivity can be avoided. In this technique short laser pulse (100ns) is used to generate excess carriers. The power of reflected microwave is measured with respect to time which is directly proportional to free carrier density.As the microwaves penetrate deep into the sample, the recorded signal represents a spatially averaged excess carrier concentration.

Photoconductivity of CdS

Single crystalline, polycrystalline semiconductors and glass materials have been used in various electronic and optoelectronic devices. Cadmium sulphide (CdS), a wide energy gap semiconductor polycrystalline in nature[12,13].It usually has a wurzite hexagonal structure and resistivity ranges from 10^{-3} to 10^{8} Ω-cm[14]. It is also reviewed that both the dark and photocurrent increases linearly with respect to applied field. It is observed that dark current is less than the photocurrent termed as positive photoconductivity. This is may be due to increase in number of free charge carriers on illumination.Single crystal CdS shows maximum response at$0.5\mu m$. Surface morphology plays an important role in study of spectral sensitivity which is constant below 0.5μm. This wavelength can be used to detect energy gap value which is found to be 2.42 eV.The wide band gap compounds shows apparent quantum efficiencies greater than unity, gainof as much as 10^{3} or 10^{4} have been observed in ZnO or CdS. The quantum efficiency or 'gain' of a semiconductor is obtained by the ratio of the electron lifetime to the transit time across the crystal.The presence of deep level trap states can prevent the electron-hole recombination and greatly prolong the lifetime of the photo carriers.

Conclusion

Photoconductivity measurement is a versatile characterization technique to probe electrical, optical properties of semiconductors. The variants in the photoconductivity measurements are steady state photoconductivity, transient photoconductivity, microwave photocurrent decay technique etc. CdS, exhibits good photo response, is widely used in optoelectronic devices.

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